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(54) **LOW HUB-TO-TIP RATIO FAN FOR A TURBOFAN GAS TURBINE ENGINE**

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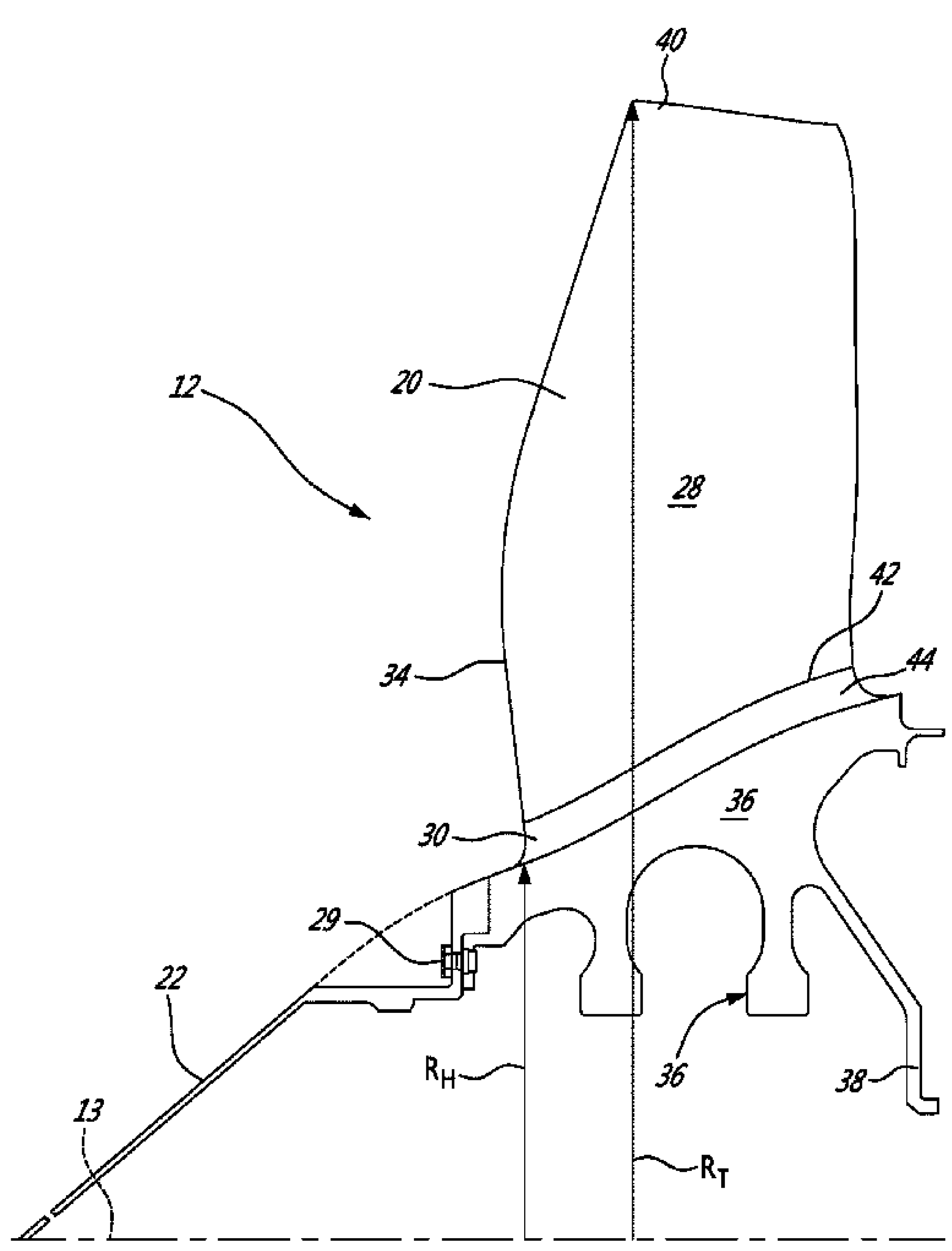
(57) **ABSTRACT**

A fan for a turbofan gas turbine engine having a low hub-to-tip ratio is disclosed. The fan includes a rotor hub and a plurality of radially extending fan blades. Each fan blade defines a hub radius (R_{HUB}), which is the radius of the leading edge at the hub relative to a centerline of the fan, and a tip radius (R_{TIP}), which is the radius of the leading edge at a tip of the fan blade relative to the centerline of the fan. The ratio of the hub radius to the tip radius (R_{HUB}/R_{TIP}) is less than 0.29. In a particular embodiment, this ratio is between 0.25 and 0.29. In another particular embodiment, this ratio is less than 0.25.

19 Claims, 2 Drawing Sheets



Related U.S. Application Data

continuation of application No. 13/687,540, filed on Nov. 28, 2012, now Pat. No. 9,303,589.

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See application file for complete search history.

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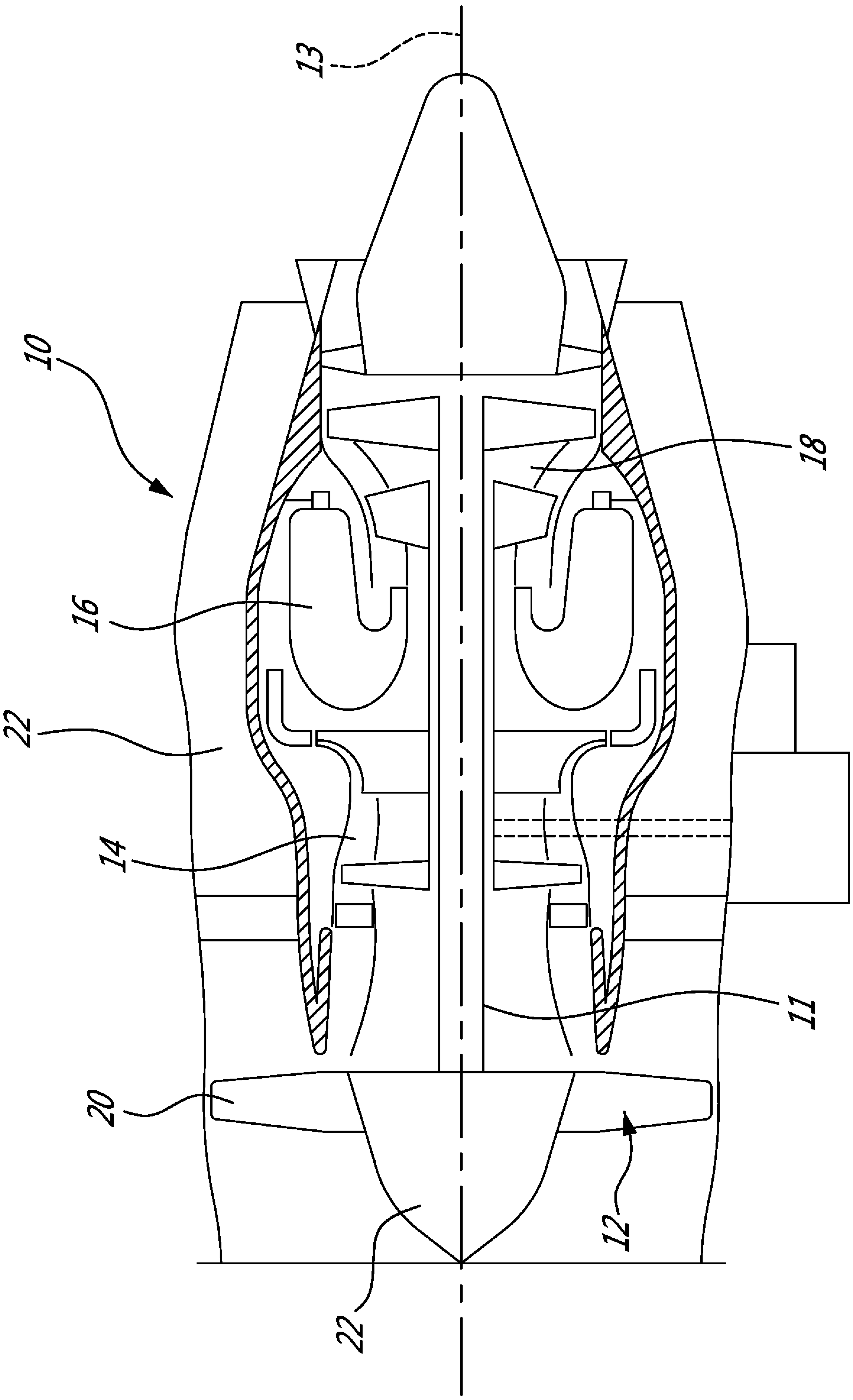

Fig-1

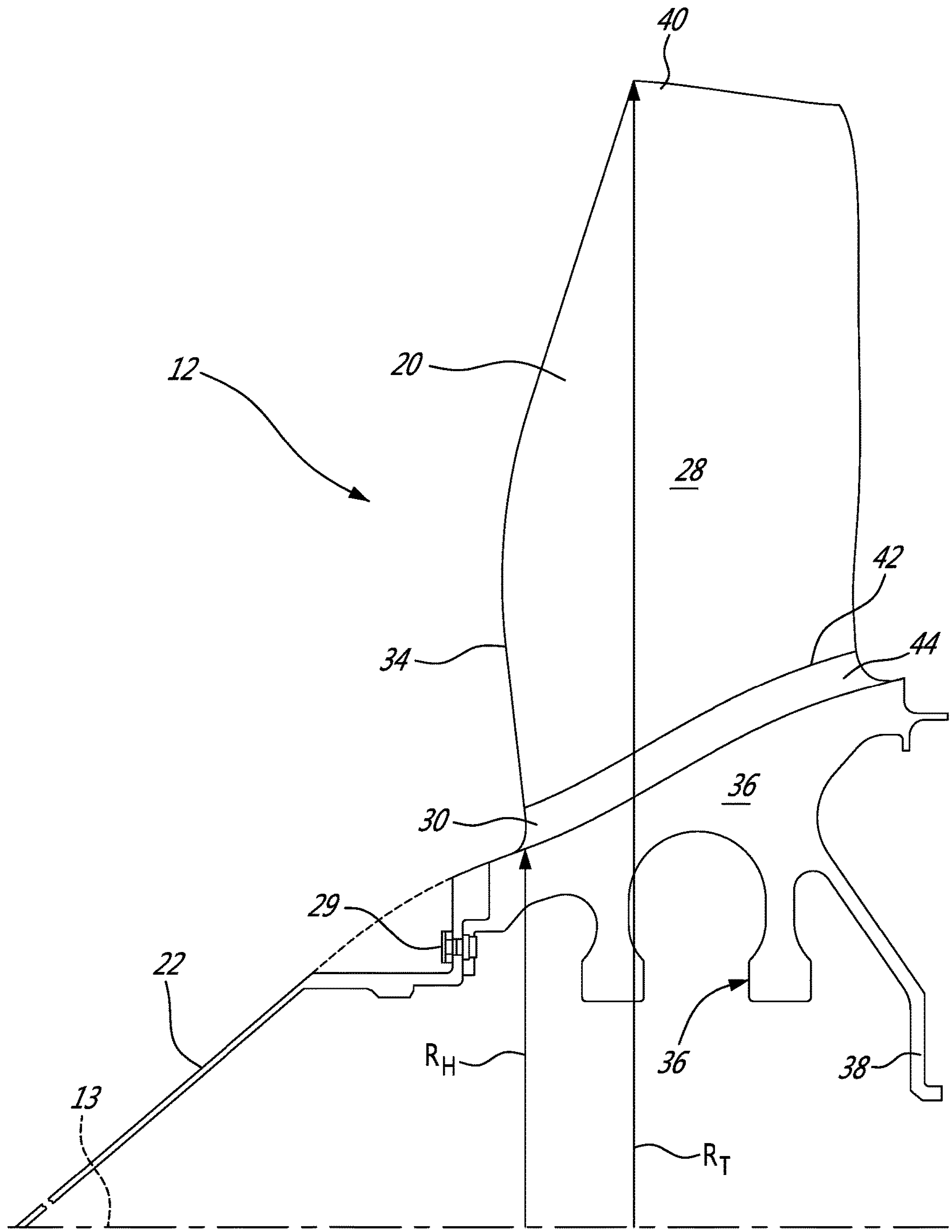

FIG. 2

LOW HUB-TO-TIP RATIO FAN FOR A TURBOFAN GAS TURBINE ENGINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. patent application Ser. No. 15/052,178 filed Feb. 24, 2016, which is itself a continuation of U.S. patent application Ser. No. 13/687,540 filed Nov. 28, 2012, now issued as U.S. Pat. No. 9,303,589, the entire content of each which is incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to turbofan engines and more particularly to fans for such engines having low hub to tip ratios.

BACKGROUND

Most gas turbine engine fans are composed of a central hub onto which a plurality of separately formed fan blades are secured. Integrated bladed rotor (IBR) fans are known for their relative lightness and therefore are desirable, however known IBR fans cannot be formed having a low hub to tip radius ratio because of limitations in manufacturing capabilities. Such a low hub to tip radius ratio is however desirable because it means the maximum diameter of the fan can be reduced without negatively effecting performance. Reducing the overall diameter of the fan reduces weight and improves the efficiency of the fan.

Therefore, while the advantages of reducing the ratio of the radius of the hub to the radius of the tip are well appreciated in terms of reducing the specific flow of air entering the leading edge of the fan, attempts to date to reduce the specific flow by reducing this ratio have not been readily possible, particularly for IBR fans. Attempts to manufacture an integrated bladed rotor (IBR) fan with a low hub to tip ratio have not been successful because of the lack of space for machine tools between the roots of the blades when the hub is also reduced in size.

SUMMARY

There is accordingly provided a fan for a turbofan gas turbine engine, the fan defining a fan centerline and comprising a rotor hub and a plurality of fan blades adapted to rotate about the fan centerline, the fan blades extending radially from the rotor hub to outer tips thereof, the fan blades circumferentially spaced apart about the rotor hub in a single axial blade row, each of the fan blades having a leading edge, a hub radius (RHUB) and a tip radius (RTIP), wherein the hub radius (RHUB) is the radius of the leading edge at the hub relative to the fan centerline, and the tip radius (RTIP) is the radius of the leading edge at the outer tip relative to the fan centerline, and wherein the ratio of the hub radius to the tip radius (RHUB/RTIP) is less than 0.29.

The ratio of the hub radius to the tip radius (RHUB/RTIP) of the fan as described above may be more particularly is less than 0.25.

The ratio of the hub radius to the tip radius (RHUB/RTIP) of the fan as described above may be more particularly between 0.25 and 0.29.

The fan as described above may be an integrally bladed rotor, the fan blades being integrally formed with the rotor hub.

The rotor hub of the integrally bladed rotor of the fan as described above may include a preform having root stubs disposed on the rotor hub at circumferential positions corresponding to at least alternate ones of said fan blades in the single axial blade row, the root stubs being formed on the rotor hub prior to the fan blades being fastened thereto.

The root stubs of the hub of the integrally bladed rotor of the fan as described above may have airfoils welded thereto to form the fan blades of the integrally bladed rotor.

The airfoils of the integrally bladed rotor of the fan as described above may be linear-friction-welded to the respective root stubs.

The preform of the integrally bladed rotor of the fan as described above may have the root stubs disposed on the rotor hub for each of the fan blades in the single blade row.

There is also provided a turbofan gas turbine engine including a fan upstream of at least one compressor and defining a fan centerline about which the fan rotates, the fan comprising: a rotor hub and a plurality of fan blades substantially radially extending from the rotor hub to outer tips thereof, the fan blades being arranged in a single blade row on the rotor hub, each of the fan blades of the single blade row having an airfoil with a leading edge, the leading edge of the airfoil extending from a hub radius (RHUB) at the rotor hub to a tip radius (RTIP) at the outer tip, and wherein a ratio of the hub radius to the tip radius (RHUB/RTIP) is less than 0.29.

The ratio of the hub radius to the tip radius (RHUB/RTIP) of the turbofan gas turbine engine as described above may be between 0.25 and 0.29.

The ratio of the hub radius to the tip radius (RHUB/RTIP) of the turbofan gas turbine engine as described above may be less than 0.25.

The fan of the turbofan gas turbine engine as described above may be an integrally bladed rotor, the airfoils of the fan blades being integrally formed with the rotor hub.

The rotor hub of the integrally bladed rotor as described above may include a preform having root stubs disposed on the rotor hub at circumferential positions corresponding to at least alternate ones of said fan blades in the single axial blade row, the root stubs being formed on the rotor hub prior to the airfoils being fastened thereto.

The airfoils of the integrally bladed rotor as described above may be welded to the root stubs to form the fan blades of the integrally bladed rotor.

The airfoils of the integrally bladed rotor as described above may be linear-friction-welded to the respective root stubs.

The preform of the integrally bladed rotor as described above may have the root stubs disposed on the rotor hub for each of the fan blades in the single blade row.

There is further provided a method of manufacturing a fan for a turbofan gas turbine engine, the fan adapted to rotate about a fan centerline axis, the method comprising: providing a rotor hub having an outer peripheral surface defining a hub radius relative to the fan centerline axis; selecting a predetermined length of fan blade airfoils, the predetermined length selected such that a ratio of the hub radius to a tip radius of the blade airfoils, as measured from the fan centerline axis to tips of the fan blade airfoils once the fan blade airfoils are mounted to the rotor hub, is less than 0.29; and positioning said fan blade airfoils to the outer peripheral surface of the rotor hub in an axially aligned single blade row, the fan blade airfoils being circumferentially spaced about the rotor hub within the axially aligned single blade row.

The method as described above may further comprise integrally forming the fan blade airfoils and the rotor hub to produce an integrally bladed rotor.

The method as described above may further comprise forming a rotor hub preform having a number of root stubs circumferentially spaced apart on a periphery of the rotor hub, the root stubs being axially aligned to define said single blade row, and fastening the fan blade airfoils to the root stubs to form fan blades integrally formed with the rotor hub.

The step of selecting of the method as described above may further comprise selecting the predetermined length of the fan blade airfoils such that the ratio of the hub radius to the tip radius of the fan blade airfoils is between 0.25 and 0.29.

The step of selecting of the method as described above may further comprise selecting the predetermined length of the fan blade airfoils such that the ratio of the hub radius to the tip radius of the fan blade airfoils is less than 0.25.

The method as described above may further comprise integrally forming circumferentially alternate ones of said fan blade airfoils with the hub preform directly to the outer peripheral surface of the rotor hub preform without root stubs, leaving alternate root stubs on the hub preform to provide access for machine tools between the circumferentially alternate ones of said fan blade airfoils.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is now made to the accompanying figures in which:

FIG. **1** is a schematic cross-sectional view of a gas turbine engine having a fan in accordance with the present disclosure; and

FIG. **2** is a partial axial cross-sectional view of an embodiment of the fan of the present disclosure.

DETAILED DESCRIPTION

FIG. **1** illustrates a turbofan gas turbine engine **10** generally comprising in serial flow communication, a fan assembly **12** through which ambient air is propelled, and a core including a compressor section **14** for pressurizing the air, a combustor **16** in which the compressed air is mixed with fuel and ignited for generating an annular stream of hot combustion gases, and a turbine section **18** for extracting energy from the combustion gases. A centerline main engine axis **13** extends longitudinally through the turbofan engine **10**.

The fan **12** propels air through both the engine core and the bypass duct **22**, and may be mounted to the low pressure main engine shaft **11**. The fan **12** includes a plurality of radially extending fan blades **20** and a central hub as will be seen, which hub has a nose cone **22** mounted thereto to protect the hub. As will be described in greater detail below, the fan **12** may be an integrally bladed rotor (IBR), in which case the fan blades **20** are integrally formed with the central hub that is fastened to the low pressure (LP) engine shaft **11** for rotation therewith.

Referring now to FIG. **2**, the fan **12** comprises a plurality of fan blades **20** integrally formed with, and substantially radially extending from, a central fan hub **36** which is mounted to an engine shaft, such as the low pressure shaft **11**, by means of one or more hub support portions **38** which are also integrally formed with the hub. Each of the blades **20** defines an airfoil **28** which has a leading edge **34** which extends from a blade root **30** to a blade tip **40**. The blade **20** is integrated with the hub **36**, i.e. such the blades **20** are integrally formed as a monolithic component with the fan hub **36** to form an IBR fan. The nose cone **22** of the engine may be fastened to an upstream end of the fan hub **36** by a plurality of fasteners **29**.

When the radius of the leading edge **30** on the hub **36** is reduced while the radius of the blade tip at **40** is maintained, the flow area (FA) of the fan **20** is increased thus reducing the specific flow (SF). As seen in FIG. **2**, the gaspath through the fan **12** is defined by the annular area between the hubs **30** and the tips **40** of the fan blades **20**. The radius of the fan hub (R_{HUB}), measured at the leading edge **34** of the blade **20**, defines the radially inner gaspath boundary and the radius of the blade tip (R_{TIP}), also measured at the leading edge **34**, defines the radially outer gaspath boundary. The specific flow of the fan **12** is therefore defined as the mass flow (MF) of air entering the leading edge of the fan **12**, divided by the flow area (FA) at the fan leading edge, normal to the engine axis **13**.

The hub to tip ratio of the fan **12** is defined as the ratio of the radius of the fan hub (R_{HUB}) at the leading edge divided by the radius of fan blade tip (R_{TIP}) at the leading edge. As shown in FIG. **2**, these radii are measured from the engine centerline axis **13**.

Thus, specific flow is determined as follows:

$$SF=MF/FA,$$

where SF is the specific flow, MF is the mass flow, and FA the flow area. Reduction of this SF of the fan is desirable as a reduced SF helps to improve the overall aerodynamic efficiency of the fan because of the lower air velocity.

A reduction in the hub to tip ratio (R_{HUB}/R_{TIP}) will therefore also cause a reduction in the specific flow (SF) of the fan. Alternatively, the radius of both the hub **36** and the blade tip **40** can be reduced while retaining the same specific flow SF. However, the ratio of the hub to tip radii is preferably reduced. Accordingly, the present IBR fan **12** has a ratio of the hub radius to the tip radius, i.e. R_{HUB}/R_{TIP}, which is at least less than 0.29. In a particular embodiment, the ratio of the hub radius to the tip radius (R_{HUB}/R_{TIP}) is between about 0.25 and about 0.29. In a further particular embodiment, the ratio of the hub radius to the tip radius (R_{HUB}/R_{TIP}) is less than or equal to 0.25.

The advantage of a lower tip radius is a smaller diameter fan and therefore a lighter weight engine. Lowering the hub leading edge radius also changes the flow angle of the airstream, and the resulting rearward sweep in the lower portion of the fan blade airfoils **28** improves performance by reducing the leading edge velocities through the sweep effect and also draws flow towards the hub **36** which helps to reduce flow separation that the blade root.

The advantage of using the integrally bladed rotor (IBR) fan **12** is its reduced weight compared to a traditional detachable bladed rotor. The machining of an IBR fan **12** with such a low hub/tip ratio is made difficult by the lack of space between the blades **20**, particularly at the blade roots **30** since the gap between the blades is much narrower the smaller the radius of the fan.

However, in one particular method of manufacturing the IBR fan **12** described herein, it has been found that by first machining a root stub **44** on the hub **36**, or more specifically on a hub preform, the lower hub radius, and more particularly the low hub to tip radius ratios described above, can be obtained because it is easier to access the radial gap between adjacent blades **20** with machine tools. The blade airfoils **28** may then be fixed to the root stubs **44** of the hub preform be welded by Linear Friction Welding (LFW), for example, along the joint line **42** as shown on the blade **20** in FIG. **2**. It has been contemplated that alternative methods may also be used, such as forming a root stub **44** only for every alternate blade, while machining the full blade **20** between each alternate root stub. This would allow sufficient access for machine tools between two alternate full blades, to machine around the around the remaining root stub.

Thus, a low-weight fan **12** as described herein is achieve, because of its integrated bladed rotor construction, and which provides a hub to tip radius ratio of at least less than 0.29, and more particularly between 0.25 and 0.29, and more particularly still a hub to tip radius ratio of 0.25 or less.

The above description is meant to be exemplary only, and one skilled in the art will recognize that changes may be made to the embodiments described while still falling within the scope of the appended claims, which define the present invention. Such modifications will be apparent to those skilled in the art, in light of a review of this disclosure.

The invention claimed is:

1. A fan for a turbofan gas turbine engine, the fan comprising a rotor hub and a plurality of fan blades extending from and being integral with the hub to form an integrally bladed rotor, the fan blades circumferentially spaced apart to form a blade row, each of the fan blades of the blade row at least partially axially overlapping circumferentially adjacent ones of the fan blades of the blade row, each of the fan blades having a leading edge extending between the rotor hub and a blade tip, and wherein a ratio of a hub radius to a tip radius (R_{HUB}/R_{TIP}) of the fan blades within the blade row is less than 0.29, wherein the hub radius (R_{HUB}) and the tip radius (R_{TIP}) are measured at the leading edge of the fan blades.

2. The fan as defined in claim **1**, wherein the ratio of the hub radius to the tip radius (R_{HUB}/R_{TIP}) is less than 0.25.

3. The fan as defined in claim **1**, wherein the ratio of the hub radius to the tip radius (R_{HUB}/R_{TIP}) is between 0.25 and 0.29.

4. The fan as defined in claim **1**, wherein the rotor hub of the integrally bladed rotor includes a preform having root stubs disposed on the rotor hub at circumferential positions corresponding to at least alternate ones of said fan blades in the single axial blade row, the root stubs being formed on the rotor hub prior to the fan blades being fastened thereto.

5. The fan as defined in claim **4**, wherein the root stubs have airfoils welded thereto to form the fan blades of the integrally bladed rotor.

6. The fan as defined in claim **5**, wherein the airfoils are linear-friction-welded to the respective root stubs.

7. The fan as defined in claim **4**, wherein the preform has said root stubs disposed on the rotor hub for each of the fan blades in the single blade row.

8. The fan as defined in claim **4**, wherein the fan blades having a rearward sweep in a radially inner portion of the leading edge.

9. A fan for a turbofan gas turbine engine, the fan comprising a rotor hub and a plurality of fan blades integral with the rotor hub to form an integrally bladed rotor having a single blade row, each of the fan blades having a leading edge extending between the rotor hub and an outer blade tip, the fan having a hub-to-tip ratio defined by a hub radius at the leading edge divided by a tip radius at the leading edge, the hub-to-tip ratio being less than 0.25.

10. The fan as defined in claim **9**, wherein the rotor hub of the integrally bladed rotor includes a preform having root stubs disposed on the rotor hub at circumferential positions corresponding to at least alternate ones of said fan blades in the single axial blade row, the root stubs being formed on the rotor hub prior to the fan blades being fastened thereto.

11. The fan as defined in claim **9**, wherein the root stubs have airfoils welded thereto to form the fan blades of the integrally bladed rotor.

12. The fan as defined in claim **11**, wherein the airfoils are linear-friction-welded to the respective root stubs.

13. The fan as defined in claim **11**, wherein the preform has said root stubs disposed on the rotor hub for each of the fan blades in the single blade row.

14. The fan as defined in claim **9**, wherein the fan blades have a rearward sweep in a radially inner portion of the leading edge.

15. A method of manufacturing an integrally bladed fan for a turbofan gas turbine engine, the integrally bladed fan adapted to rotate about a fan centerline axis, the method comprising: providing a rotor hub having an outer peripheral surface defining a hub radius relative to the fan centerline axis; providing a plurality of fan blade airfoils having a predetermined length; and integrally forming the fan blade airfoils and the rotor hub to produce a blade row of the fan blade airfoils on the rotor hub, wherein each of the fan blade airfoils of the blade row at least partially axially overlaps circumferentially adjacent ones of the fan blade airfoils within the blade row, the fan blade airfoils of the blade row thus formed providing a ratio of the hub radius to a tip radius of the fan blade airfoils, measured from the fan centerline axis to tips of the fan blade airfoils at leading edges thereof, of less than 0.29.

16. The method of claim **15**, further comprising forming a rotor hub preform having a number of root stubs circumferentially spaced apart on a periphery of the rotor hub, the root stubs being axially aligned to define said single blade row, and fastening the fan blade airfoils to the root stubs to form fan blades integrally formed with the rotor hub.

17. The method as defined in claim **15**, further comprising selecting the predetermined length of the fan blade airfoils such that the ratio of the hub radius to the tip radius is between 0.25 and 0.29.

18. The method as defined in claim **15**, further comprising selecting the predetermined length of the fan blade airfoils such that the ratio of the hub radius to the tip radius is less than 0.25.

19. The method as defined in claim **15**, further comprising integrally forming circumferentially alternate ones of said fan blade airfoils with the hub preform directly to the outer peripheral surface of the rotor hub preform without root stubs, leaving alternate root stubs on the hub preform to provide access for machine tools between the circumferentially alternate ones of said fan blade airfoils.

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